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(54) **PERPENDICULAR MAGNETIC RECORDING MEDIA AND METHODS FOR PRODUCING THE SAME**

(75) Inventors: **Hi Shin**, Singapore (SG); **Iwao Okamoto**, Singapore (SG)

(73) Assignee: **WD Media (Singapore) Pte. Ltd.**, Irvine, CA (US)

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See application file for complete search history.

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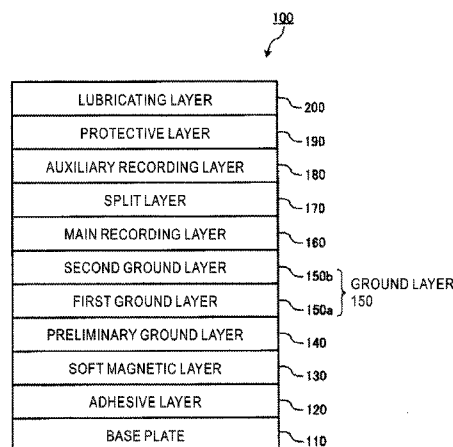
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(57) **ABSTRACT**

[Problem] An object is to provide a perpendicular magnetic recording medium that can realize both improvement in crystal orientation and refinement of crystal grain size and can achieve a higher recording density and a higher SN ratio, and a method of manufacturing the same.

[Solution] A perpendicular magnetic recording medium **100** of the present invention is a perpendicular magnetic recording medium **100** having a base plate **100**, and a laminate film including a first ground layer **150a** provided on the base plate **100**, a second ground layer **150b** provided on the first ground layer **150a**, and a main recording layer **160** provided on the second ground layer **150b** and containing a magnetic material having a granular structure, wherein the magnetic material which constitutes the main recording layer **160** contains a CoCrPt alloy, and a material which constitutes the second ground layer **150b** contains an Ru—Co oxide alloy.

**11 Claims, 5 Drawing Sheets**



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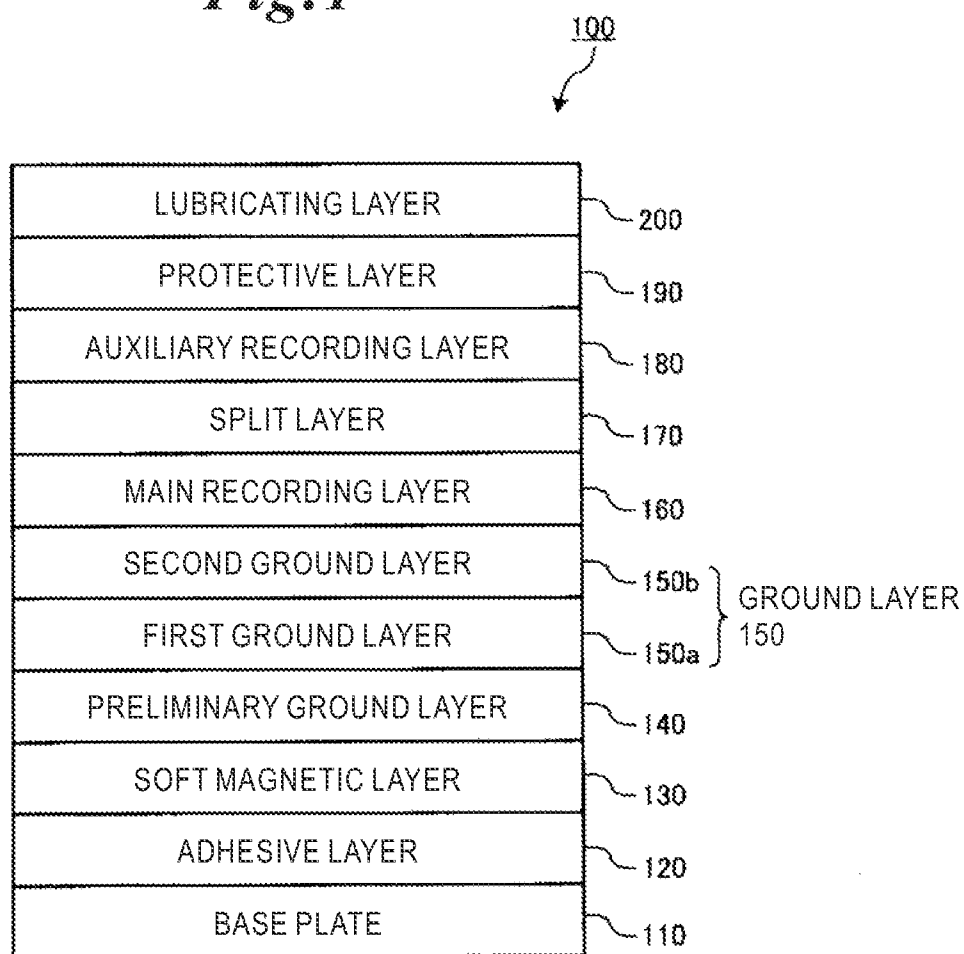
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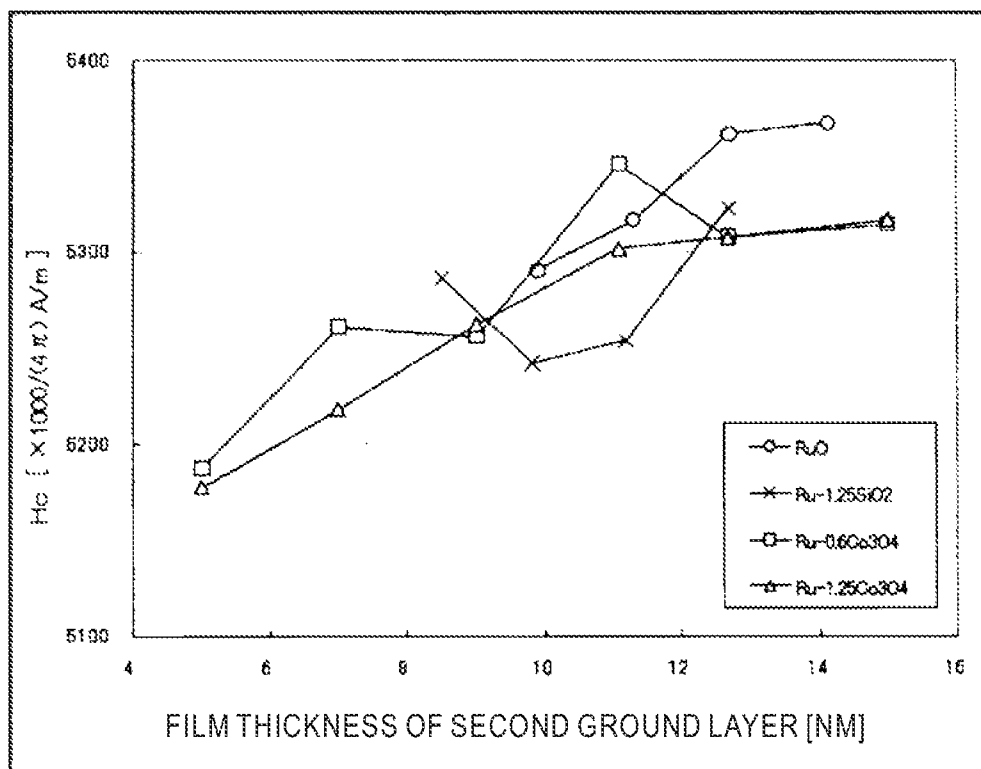
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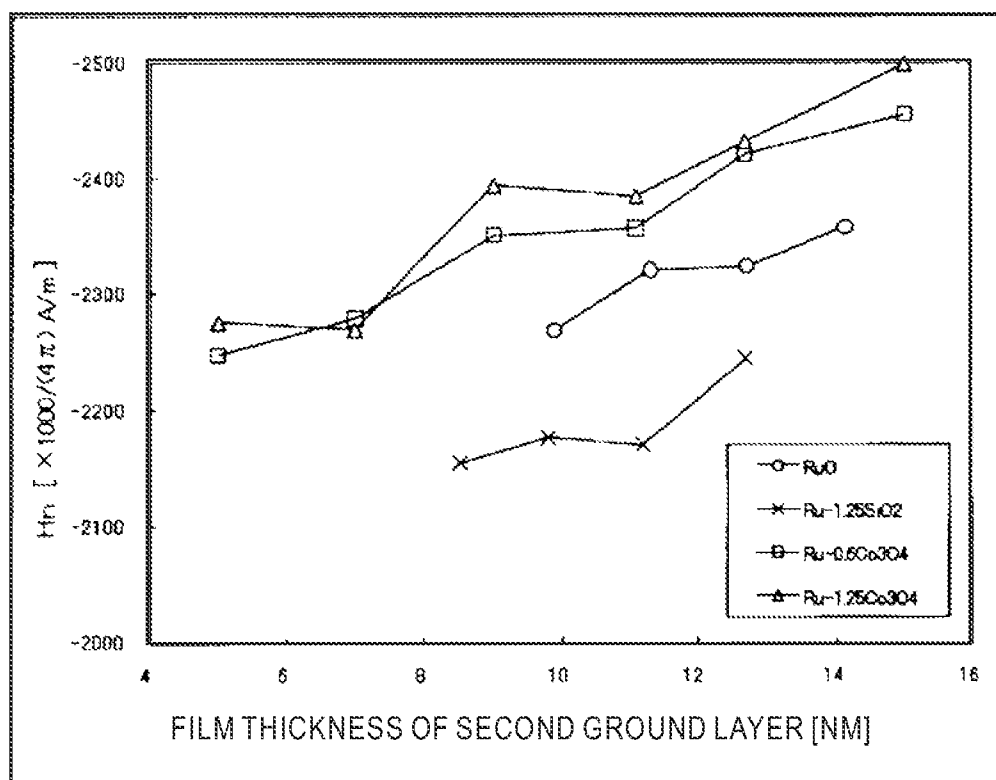
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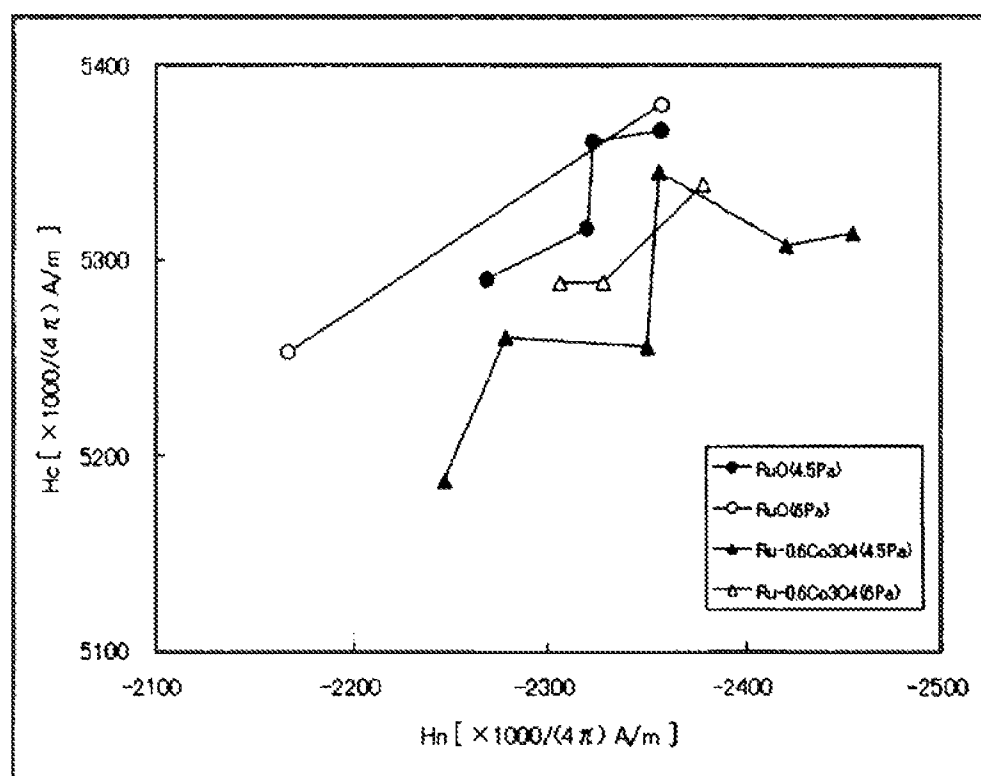
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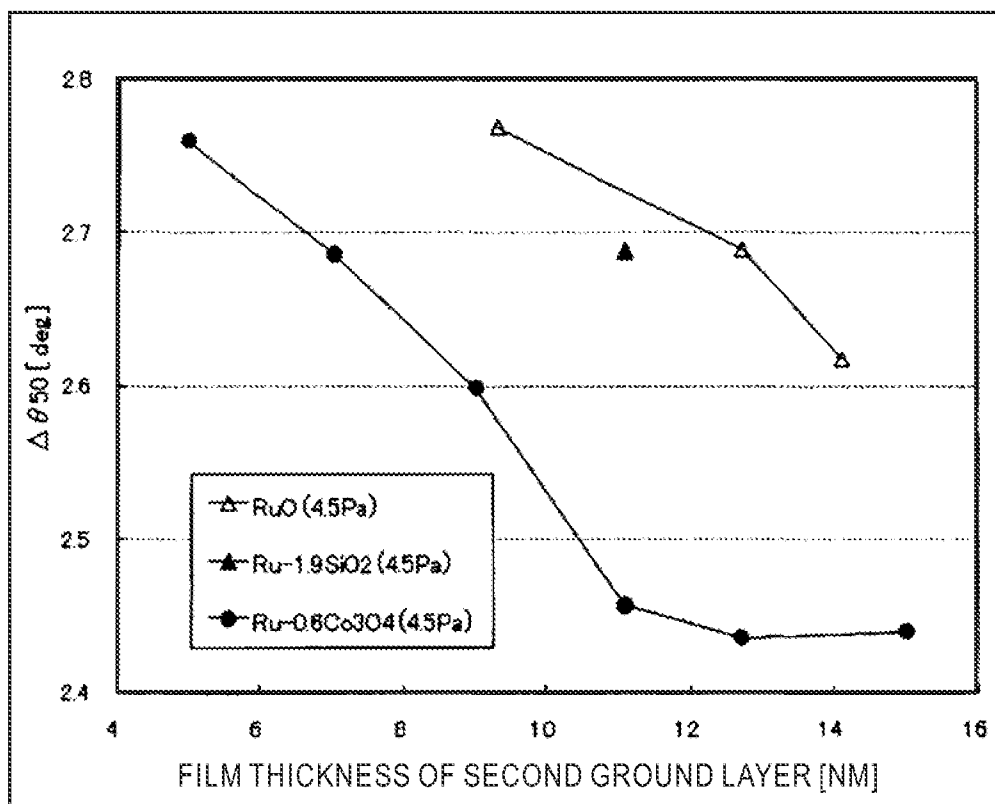
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*Fig. 1*

*Fig. 2*

*Fig.3*

*Fig. 4*

*Fig.5*

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# PERPENDICULAR MAGNETIC RECORDING MEDIA AND METHODS FOR PRODUCING THE SAME

## TECHNICAL FIELD

The present invention relates to a perpendicular magnetic recording medium installed in an HDD (hard disk drive) or the like of a perpendicular magnetic recording type, and a method of manufacturing the same.

## BACKGROUND ART

With increase in capacity of information processing in recent years, various information recording technologies have been developed. In particular, the surface recording density of an HDD using a magnetic recording technology is continuously increasing at an annual rate of approximately 100%. Recently, an information recording capacity exceeding 320 gigabytes/platter with a 2.5-inch diameter of a magnetic recording medium for use in an HDD or the like has been demanded, and in order to satisfy such a demand, an information recording density exceeding 500 gigabytes/square inch is required to be realized.

In order to achieve high recording density in a magnetic recording medium for use in an HDD or the like, a perpendicular magnetic recording type has been suggested in recent years. In a perpendicular magnetic recording medium used for the perpendicular magnetic recording type, an easy axis of magnetization of a granular magnetic layer (a magnetic layer having a granular structure) is adjusted so as to be oriented in a perpendicular direction with respect to a base surface. The perpendicular magnetic recording type is more suitable for increasing a recording density than a conventional in-plane magnetic recording type, since the perpendicular magnetic recording type can suppress a so-called thermal fluctuation phenomenon that a recording signal is lost due to the thermal stability of the recording signal is impaired by a superparamagnetic phenomenon.

As a perpendicular magnetic recording medium used for the perpendicular magnetic recording type, a magnetic recording medium where a backing layer, an orientation control layer, a magnetic recording layer, and a protective layer are stacked on a non-magnetic base plate has been suggested (for example, see Patent Document 1). In such a magnetic recording medium, the magnetic recording layer is constituted with use of a Co alloy material having a hexagonal close packed structure (hcp structure), and the orientation control layer is composed of an intermediate layer that improves the characteristics of the magnetic recording layer and a seed layer that adjusts the crystal orientations of the intermediate layer and the magnetic recording layer. The intermediate layer is deposited by sputtering using Ru or a Ru alloy having the hcp structure, and composed of a first intermediate layer (first ground layer) that is formed under a low-pressure condition, and a second intermediate layer (second ground layer) that is formed under a high-pressure condition.

## PRIOR ART DOCUMENT

Patent Document

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2009-059431

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## SUMMARY OF THE INVENTION

### Problem to be Solved by the Invention

By the way, for the magnetic recording medium of the perpendicular magnetic recording type, improvement of crystal orientation and refinement of crystal grain size (particle separation) of the magnetic recording layer are important in order to realize a higher recording density and a higher SN ratio. In the magnetic recording medium according to Patent Document 1, the crystal orientation is refined by forming the first intermediate layer under a low-pressure condition and the crystal grain size of the magnetic recording layer is refined by forming the second intermediate layer under a high-pressure condition to suppress bonding between crystal grains by a void generated therebetween.

In the magnetic recording medium according to Patent Document 1, however, since forming the second intermediate layer under a high-pressure condition is required for refinement of crystal grain size of the magnetic recording layer, there is the problem that the crystal orientation of a Co alloy material or the like used as a material of the magnetic recording layer degrades as the pressure at the time of film formation increases. This causes the problem that improvement of the crystal orientation of the magnetic recording layer cannot necessarily be sufficient, since the contribution of the second intermediate layer to improvement of the crystal orientation of the magnetic recording layer is smaller than that of the first intermediate layer.

The present invention has been made in view of these circumstances, and an object thereof is to provide a perpendicular magnetic recording medium that can realize both improvement of crystal orientation and refinement of crystal grain size and can achieve a higher recording density and a higher SN ratio, and a method of manufacturing the same.

### Means for Solving the Problem

A perpendicular magnetic recording medium of the present invention is a perpendicular magnetic recording medium having a base plate, and a laminate film including a first ground layer provided on the base plate, a second ground layer provided on the first ground layer, and a magnetic layer provided on the second ground layer and containing a magnetic material having a granular structure, wherein the magnetic material which constitutes the magnetic layer contains a CoCrPt alloy, and a material which constitutes the second ground layer contains an Ru—Co oxide alloy.

Regarding the perpendicular magnetic recording medium of the present invention, it is preferred that the material which constitutes the second ground layer be an Ru—xCoO alloy, where x ranges from 0.2 mol to 5 mol.

Regarding the perpendicular magnetic recording medium of the present invention, it is preferred that the film thickness of the second ground layer ranges from 2 nm to 20 nm.

Regarding the perpendicular magnetic recording medium of the present invention, it is preferred that the second ground layer be formed by sputtering using an Ru—CoO alloy or an Ru—Co<sub>3</sub>O<sub>4</sub> alloy as a target.

Regarding the perpendicular magnetic recording medium of the present invention, it is preferred that the second ground layer be formed under the condition of an Ar atmosphere at a gas pressure in the range of 3 Pa to 10 Pa.

A method of manufacturing a perpendicular magnetic recording medium of the present invention is a method of manufacturing a perpendicular magnetic recording medium having a base plate, and a laminate film including a first

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ground layer provided on the base plate, a second ground layer provided on the first ground layer, and a magnetic layer provided on the second ground layer and containing a magnetic material having a granular structure, wherein the second ground layer is formed by sputtering using an Ru—Co oxide alloy as a target.

#### Effect of the Invention

According to the present invention, it is possible to provide a perpendicular magnetic recording medium that can realize both improvement in crystal orientation and refinement of crystal grain size and can achieve a higher recording density and a higher SN ratio, and a method of manufacturing the same.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a descriptive diagram of a laminate structure of a perpendicular magnetic recording medium according to an embodiment of the present invention;

FIG. 2 is a graph showing a relationship between the film thickness of a second ground layer and a coercive force (Hc);

FIG. 3 is a graph showing a relationship between the film thickness of the second ground layer and a nucleation magnetic field (Hn);

FIG. 4 is a graph showing a relationship between the coercive force (Hc) and the nucleation magnetic field (Hn); and

FIG. 5 is a graph showing a relationship between the film thickness of the second ground layer and crystal orientation dispersion ( $\Delta S$ ).

#### EMBODIMENT OF THE INVENTION

An embodiment of the present invention will be described in detail below with reference to the attached drawings.

FIG. 1 is a diagram for describing the configuration of a perpendicular magnetic recording medium 100 according to the embodiment of the present invention. The perpendicular magnetic recording medium 100 shown in FIG. 1 has a laminate film including at least a magnetic layer on a base plate 110. The laminate film is mainly composed of an adhesive layer 120, a soft magnetic layer 130, a preliminary ground layer 140, a ground layer 150 (a first ground layer 150a, a second ground layer 150b), a main recording layer 160, a split layer 170, an auxiliary recording layer 180, a protective layer 190, and a lubricating layer 200.

As the base plate 110, for example, a glass disk molded in a disk shape by direct-pressing amorphous aluminosilicate glass can be used. Note that the kind, size, thickness, and others of the glass disk are not particularly restricted. A material of the glass disk can be, for example, aluminosilicate glass, soda lime glass, soda aluminosilicate glass, aluminoborosilicate glass, borosilicate glass, quartz glass, chain silicate glass, or glass ceramic, such as crystallized glass. This glass disk is sequentially subjected to grinding, polishing, and chemical strengthening, thereby allowing the smooth non-magnetic base plate 110 made of a chemically-strengthened glass disk to be obtained.

On the base plate 110, the adhesive layer 120 to the auxiliary recording layer 180 are sequentially formed by DC magnetron sputtering, and the protective layer 190 can be formed by CVD. Thereafter, the lubricating layer 200 can be formed by dip coating. The configuration of each layer will be described below.

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The adhesive layer 120 is formed in contact with the base plate 110, and provided with a function of increasing adhesion strength between the soft magnetic layer 130 formed thereon and the base plate 110. It is preferred that the adhesive layer 120 be a film of amorphous alloy, such as a CrTi-type amorphous alloy, a CoW-type amorphous alloy, a CrW-type amorphous alloy, a CrTa-type amorphous alloy, or a CrNb-type amorphous alloy. The film thickness of the adhesive layer 120 can be set, for example, in the range of approximately 2 nm to 20 nm. The adhesive layer 120 may be a single layer or may have a laminate structure.

The soft magnetic layer 130 acts to converge a writing magnetic field from the head when a signal is recorded in a perpendicular magnetic recording type, thereby supporting easy writing of the signal to a magnetic recording layer and density growth. As a soft magnetic material, not only a cobalt-type alloy, such as CoTaZr, but also a material that exhibits a soft magnetic property, such as an FeCo-type alloy, such as FeCoCrB, FeCoTaZr, or FeCoNiTaZr, or a NiFe-type alloy, can be used. The soft magnetic layer 130 can be configured to be provided with AFC (antiferromagnetic exchange coupling) by interposing a spacer layer made of Ru approximately in the middle of the soft magnetic layer 130. This configuration can reduce perpendicular components of magnetization extremely, thereby reducing noise generated from the soft magnetic layer 130. In the configuration of interposition of the spacer layer in the soft magnetic layer 130, the film thickness of the soft magnetic layer 130 can be set to about 0.3 nm to 0.9 nm for the spacer layer and about 10 nm to 50 nm for each of upper and lower layers of the soft magnetic material.

The preliminary ground layer 140 is provided with a function of promoting crystal orientation of the ground layer 150 formed thereon and a function of controlling a fine structure, such as grain size. Though the preliminary ground layer 140 may have an hcp structure, it is preferred that the preliminary ground layer 140 have a face-centered cubic structure (fcc structure) in which a (111) face is oriented so as to be parallel to a main surface of the base plate 110. As a material of the preliminary ground layer 140, for example, Ni, Cu, Pt, Pd, Ru, Co, Hf, or an alloy containing these metals as a main component and added with at least one of V, Cr, Mo, W, Ta, and the like can be selected. Specifically, NiV, NiCr, NiTa, NiW, NiVCr, CuW, CuCr, or the like can be suitably selected. The film thickness of the preliminary ground layer 140 can be set in the range of about 1 nm to 20 nm. The preliminary ground layer 140 may also have a laminate structure.

The ground layer 150 has an hcp structure, is provided with a function of promoting crystal orientation of magnetic crystal grains in the hcp structure of the main recording layer 160 formed thereon, and a function of controlling a fine structure, such as grain size, and serves as a so-called foundation for a granular structure of the main recording layer. Ru has the same hcp structure as Co, and has a crystal lattice space close to that of Co, and therefore Ru can successfully orient magnetic particles containing Co as a main component. Therefore, higher crystal orientation of the ground layer 150 can improve the crystal orientation of the main recording layer 160 more, and refinement of grain size of the ground layer 150 can cause refinement of grain size of the main recording layer. Though Ru is a typical material of the ground layer 150, a metal, such as Cr or Co, or an oxide can also be added to the ground layer 150. The film thickness of the ground layer 150 can be set in the range of about 5 nm to 40 nm, for example.

The ground layer **150** is composed of an Ru-containing film of a two-layer structure, and includes the first ground layer **150a** deposited on the preliminary ground layer **140** and the second ground layer **150b** deposited on the first ground layer **150a**. The first ground layer **150a** and the second ground layer **150b** are formed under different film formation conditions. An Ar gas pressure is made relatively higher when the second ground layer **150b** on the upper side is formed than when the first ground layer **150a** on the lower side is formed. Since a free travel distance of sputtered plasma ions becomes shorter as the gas pressure increases, a film formation rate becomes slower, and crystal orientation can be improved. Further, as the gas pressure increases, the size of a crystal lattice becomes smaller. Since the size of a crystal lattice of Ru is larger than that of Co, the crystal orientation of a granular layer of Co can be improved further by making the crystal lattice of Ru smaller so as to become closer to that of Co.

The second ground layer **150b** is composed of a material containing an Ru—Co oxide alloy. Since the second ground layer **150b** contains an Ru—Co oxide alloy, a crystal grain boundary made of oxide is formed in the second ground layer **150b** to promote interparticle separation, and also functioning to improve crystal orientations of Ru which constitutes the ground layer **150** and the main recording layer **160**. This is presumably because Co atoms generated by partial decomposition (reduction) of a Co oxide combines with Ru atoms to form an Ru—Co compound (alloy) at a step of film formation of the second ground layer **150b** by sputtering.

Further, it is preferred that the second ground layer **150b** be an Ru-xCoO alloy (x ranges from 0.2 mol to 5 mol). The second ground layer **150b** having a composition in this range makes both an effect of promotion of interparticle separation and an effect of improvement of crystal orientation possible.

It is preferred that the film thickness of the second ground layer **150b** be in the range of 2 nm to 20 nm. Since the film thickness of the second ground layer **150b** in the range of 2 nm to 20 nm maximizes both the effect of promotion of interparticle separation and the effect of improvement of crystal orientation, recording and reproduction characteristics of the medium are improved. It is particularly preferred that the film thickness of the second ground layer **150b** be in the range of 5 nm to 15 nm, and it is further preferred that it be in the range of 5 nm to 10 nm.

Further, it is preferred that the second ground layer **150b** be formed by sputtering with use of an Ru—CoO alloy or an Ru—Co<sub>3</sub>O<sub>4</sub> alloy as a target. Since sputtering with use of these targets causes the Co oxide to segregate in an Ru crystal grain boundary, separation or isolation of Ru crystal grains, or Co crystal grains grown thereon is promoted. Therefore, a perpendicular magnetic recording medium having a high SN ratio can be realized.

Further, it is preferred that the second ground layer **150b** be formed under the condition of an Ar atmosphere at a gas pressure of 3 Pa to 10 Pa. Since formation of the second ground layer **150b** under this condition causes a void between crystal grains of the second ground layer **150b**, separation or isolation between the grains is achieved, so that a medium noise characteristic can be reduced.

Further, the gas pressure for sputtering of the first ground layer **150a** and the gas pressure for sputtering of the second ground layer **150b** may be made different from each other. Specifically, by making the gas pressure for sputtering of forming the second ground layer **150b** higher than the Ar gas pressure for forming the first ground layer **150a** side, the

grain size of a magnetic particle can be refined with crystal orientation of the main recording layer **160** thereon kept well.

The main recording layer **160** has a columnar granular structure in which a grain boundary is formed by segregation of a non-magnetic substance containing an oxide as a main component around magnetic particles of a ferromagnetic body containing a Co—Pt-type alloy as a main component. For example, by film formation using a target obtained by mixing SiO<sub>2</sub> or TiO<sub>2</sub> into a CoCrPt-type alloy, a granular structure in which a grain boundary is formed by segregation of SiO<sub>2</sub> or TiO<sub>2</sub> that is a non-magnetic substance around magnetic particles (grains) made of the CoCrPt-type alloy and in which the magnetic particles are grown in a columnar shape can be formed.

Note that the above-described substances used in the main recording layer **160** are examples, not limitations. The CoCrPt-type alloy may be an alloy obtained by adding at least one of B, Ta, Cu, and the like in CoCrPt. Further, the non-magnetic substance for forming a grain boundary can be an oxide, such as silicon oxide (SiO<sub>2</sub>), titanium oxide (TiO<sub>2</sub>), chrome oxide (Cr<sub>2</sub>O<sub>3</sub>), zirconium oxide (ZrO<sub>2</sub>), tantalum oxide (Ta<sub>2</sub>O<sub>5</sub>), cobalt oxide (CoO or Co<sub>3</sub>O<sub>4</sub>), by way of example. It is also possible to use not only one kind of oxide but also two or more kinds of oxides in combination.

The split layer **170** is provided between the main recording layer **160** and the auxiliary recording layer **180**, and has a function of adjusting the strength of exchange coupling between these layers. Since this can adjust the strength of magnetic coupling between the main recording layer **160** and the auxiliary recording layer **180** and between adjacent magnetic particles in the main recording layer **160**, it is possible to improve recording and reproduction characteristics, such as an overwrite characteristic or an SNR characteristic while keeping a magnetostatic value, such as Hc or Hn relating to an anti-thermal-fluctuation characteristic.

It is preferred that, in order to prevent inheritance of crystal orientation from lowering, the split layer **170** be a layer containing Ru or Co with an hcp structure as a main component. As an Ru-type material, other than Ru, a material obtained by adding another metal element, oxygen, or an oxide in Ru can be used. As a Co-type material, a CoCr alloy or the like can be used. Specifically, Ru, RuCr, RuCo, Ru—SiO<sub>2</sub>, Ru—WO<sub>3</sub>, Ru—TiO<sub>2</sub>, CoCr, CoCr—SiO<sub>2</sub>, CoCr—TiO<sub>2</sub>, or the like can be used. Note that, though a non-magnetic material is generally used for the split layer **170**, the split layer **170** may have weak magnetism. Further, in order to obtain a good exchange coupling strength, it is preferred that the film thickness of the split layer **170** be in the range of 0.2 nm to 1.0 nm.

The auxiliary recording layer **180** is a magnetic layer magnetically approximately continuous in an in-plane direction of the main surface of the base plate. Since the auxiliary recording layer **180** has magnetic interaction (exchange coupling) with the main recording layer **160**, it is possible to adjust a magnetostatic characteristic, such as a coercive force Hc or an inverted magnetic domain nucleation magnetic field Hn, which aims at improving the anti-thermal-fluctuation characteristic, the OW (overwrite) characteristic, and the SNR. As a material of the auxiliary recording layer **180**, a CoCrPt-type alloy can be used, and further an additive, such as B, Ta, or Cu, may be added therein. Specifically, CoCrPt, CoCrPtB, CoCrPtTa, CoCrPtCu, CoCrPtCuB, or the like can be used. The film thickness of the auxiliary recording layer **180** can be set, for example, in the range of 3 nm to 10 nm.

Note that “magnetically continuous” means that magnetism is continuous without interruption. “Approximately continuous” means that, when seen as a whole, the auxiliary recording layer **180** does not have to be a single magnet and may have partially-discontinuous magnetism. That is, the auxiliary recording layer **180** is only required to have magnetism continuous over (so as to cover) a plurality of aggregates of magnetic particles. As long as this condition is satisfied, the auxiliary recording layer **180** may have a structure in which Cr has been segregated, for example.

The protective layer **190** is a layer for protecting the perpendicular magnetic recording medium **100** from an impact from the magnetic head or corrosion. The protective layer **190** can be formed by forming a film containing carbon by CVD. A carbon film formed by CVD is preferred, since in general it is improved in film hardness as compared with one formed by sputtering, and therefore can protect the perpendicular magnetic recording medium **100** more effectively from an impact from the magnetic head. The film thickness of the protective layer **190** can be set, for example, in the range of 2 nm to 6 nm.

The lubricating layer **200** is formed to prevent the protective layer **190** from being damaged when the magnetic head comes in contact with the surface of the perpendicular magnetic recording medium **100**. For example, the lubricating layer **200** can be formed by dip-coating PFPE (perfluoropolyether). The film thickness of the lubricating layer **200** can be set, for example, in the range of 0.5 nm to 2.0 nm.

Here, a relationship between the film thickness of the second ground layer **150b** and coercive force ( $H_c$ ) was examined. The result is shown in FIG. 2. FIG. 2 shows a case where the second ground layer **150b** contained RuO, a case where the second ground layer **150b** contained Ru-1.25SiO<sub>2</sub>, a case where the second ground layer **150b** contained Ru-0.6Co<sub>3</sub>O<sub>4</sub>, and a case where the second ground layer **150b** contained Ru-1.25Co<sub>3</sub>O<sub>4</sub>. Note that the coercive force was measured at room temperature by using a Kerr-effect-type magnetometer. At that time, the magnetic field was swept from +15000 Oe ( $1000/(4\pi)$  A/m) to -15000 Oe ( $1000/(4\pi)$  A/m) at a constant rate for 20 seconds. As can be seen from FIG. 2, the coercive forces in the cases where the second ground layer **150b** contained an Ru—Co oxide alloy were approximately equal to those in the cases where the second ground layer **150b** contained RuO or Ru—SiO<sub>2</sub>.

Next, a relationship between the film thickness of the second ground layer **150b** and a nucleation magnetic field ( $H_n$ ) was examined. The result is shown in FIG. 3. As shown in FIG. 3, the nucleation magnetic field was weaker in the case where the second ground layer **150b** contained Ru-1.25SiO<sub>2</sub> than in the case where the second ground layer **150b** contained RuO (the absolute value lowered by up to 100 Oe ( $1000/(4\pi)$  A/m)). Further, the nucleation magnetic field was stronger in the case where the second ground layer **150b** contained Ru-0.6Co<sub>3</sub>O<sub>4</sub> or in the case where the second ground layer **150b** contained Ru-1.25Co<sub>3</sub>O<sub>4</sub> than in the case where the second ground layer **150b** contained RuO (the absolute value increased by 50 Oe ( $1000/(4\pi)$  A/m) to 100 Oe ( $1000/(4\pi)$  A/m)). The nucleation magnetic field was measured at room temperature by using a Kerr effect evaluation apparatus. As can be seen from FIG. 3, a stronger nucleation magnetic field than in the cases where the second ground layer **150b** contained RuO or Ru—SiO<sub>2</sub> was obtained by the second ground layer **150b** was an Ru—Co oxide alloy. Since a medium fringe characteristic (an anti-erase characteristic at the time of writing on an adjacent track) is improved more as the nucleation magnetic field

becomes stronger, the second ground layer **150b** containing the Ru—Co oxide alloy can be expected to improve the medium fringe characteristic.

Next, a relationship between the coercive force ( $H_c$ ) and the nucleation magnetic field ( $H_n$ ) was examined. The result is shown in FIG. 4. As shown in FIG. 4, even at the gas pressure of 4.5 Pa and even at the gas pressure of 6 Pa, an absolute value  $|H_n|$  of the nucleation magnetic field at the same  $H_c$  increased (+50 Oe ( $1000/(4\pi)$  A/m) to 100 Oe ( $1000/(4\pi)$  A/m)) in the case where the second ground layer **150b** contained Ru-0.6Co<sub>3</sub>O<sub>4</sub> as compared with the case where the second ground layer **150b** contained RuO. As described above, since the increase of the nucleation magnetic field ( $H_n$ ) is obtained even at an equal coercive force ( $H_c$ ), the second ground layer **150b** containing the Ru—Co oxide alloy can be expected to improve the fringe characteristic without causing deterioration of the OW characteristic of the medium.

Next, a relationship between the film thickness of the second ground layer **150b** and crystal orientation dispersion ( $\Delta 50$ ) was examined. The result is shown in FIG. 5. FIG. 5 shows a case where the second ground layer **150b** contained RuO (2 kppm) (a gas pressure of 4.5 Pa), a case where the second ground layer **150b** contained Ru-1.9SiO<sub>2</sub> (a gas pressure of 4.5 Pa), and a case where the second ground layer **150b** contained Ru-0.6Co<sub>3</sub>O<sub>4</sub> (a gas pressure of 4.5 Pa). Note that the crystal orientation dispersion was measured by using SmartLab, an X-ray diffractometer, manufactured by RIGAKU Corporation with an X-ray power of 45 kV and 200 mA. As can be seen from FIG. 5, the crystal orientation dispersion ( $\Delta 50$ ) was lower and accordingly the orientation was higher in the case where the second ground layer **150b** contained an Ru—Co oxide alloy than in the cases where the second ground layer **150b** was RuO or Ru—SiO<sub>2</sub>.

Thus, it was found that, in the case where a material which constituted the second ground layer contained the Ru—Co oxide alloy, magnetic characteristics equivalent to those in the case where the second ground layer **150b** was RuO or Ru—SiO<sub>2</sub> were produced and refinement of crystal grain size was achieved. It was also found that, in the case where a material which constituted the second ground layer contained the Ru—Co oxide alloy, crystal orientation higher than that in the case where the second ground layer **150b** was RuO or Ru—SiO<sub>2</sub> was produced. Therefore, a perpendicular magnetic recording medium having such a second ground layer can realize both improvement in crystal orientation and refinement of crystal grain size and can achieve a higher recording density and a higher SN ratio.

(Example)

Next, an example performed to clarify the effect of the present invention will be described.

A glass disk was formed by molding amorphous aluminosilicate glass in a disk shape by direct-pressing. This glass disk was sequentially subjected to grinding, polishing, and chemical strengthening, and thus a base plate which was a smooth non-magnetic disk base made of a chemically-strengthened glass disk was obtained. The base plate was a base plate for a 2.5-inch magnetic disk being 65 mm in diameter, 20 mm in inner diameter, and 0.635 mm in disk thickness. From observation of surface roughness of the base plate obtained with an AFM (atomic force microscope), it was confirmed that the base plate had a smooth surface with 2.18 nm in  $R_{max}$  and 0.18 in  $R_a$ . Note that  $R_{max}$  and  $R_a$  adhere to Japanese Industrial Standards (JIS).

Next, the adhesive layer **120**, the soft magnetic layer **130**, the preliminary ground layer **140**, the first ground layer

**150a**, the second ground layer **150b**, the main recording layer **160**, the split layer **170**, and the auxiliary recording layer **180** were sequentially formed on the base plate **110** in an Ar atmosphere by DC magnetron sputtering with use of a vacuumed film forming device. Note that an Ar gas pressure at the film formation time was 0.6 Pa, unless otherwise described.

Specifically, as the adhesive layer **120**, a 10 nm-thick Cr-50Ti film was formed. As the soft magnetic layer **130**, 20 nm-thick 92(40Fe-60Co)-3Ta-5Zr films were formed with a 0.7 nm-thick Ru layer interposed therebetween. As the preliminary ground layer **140**, an 8 nm-thick Ni-5W film was formed. As the first ground layer **150a**, a 10 nm-thick Ru film was formed at an Ar gas pressure of 0.6 Pa. As the second ground layer **150b**, an 8 nm-thick Ru—Co<sub>3</sub>O<sub>4</sub> was formed at an Ar gas pressure of 4.5 Pa. As the main recording layer **160**, a 2 nm-thick 90(70Co-10Cr-20Pt)-10 (Cr<sub>2</sub>O<sub>3</sub>) film was formed at an Ar gas pressure of 3 Pa, and thereon a 12 nm-thick 90(72Co-10Cr-18Pt)-5(SiO<sub>2</sub>)-5 (TiO<sub>2</sub>) film was further formed at an Ar gas pressure of 3 Pa. As the split layer **170**, a 0.3 nm-thick Ru film was formed. As the auxiliary recording layer **180**, a 6 nm-thick 62Co-18Cr-15Pt-5B film was formed.

The protective layer **190** with a thickness of 4 nm was formed on the auxiliary recording layer **180** by using C<sub>2</sub>H<sub>4</sub> by CVD, and a superficial layer thereof was subjected to nitriding treatment. Next, the lubricating layer **200** was formed to have a thickness of 1 nm by using PFPE (perfluoropolyether) by dip coating. In this manner, a perpendicular magnetic recording medium according to the example was manufactured.

#### (Comparative Example)

A perpendicular magnetic recording medium of a comparative example was formed in the same manner as the example, except that, as the first ground layer **150a**, a 10 nm-thick Ru film was formed at an Ar gas pressure of 0.6 Pa, and, as the second ground layer **150b**, an 8 nm-thick Ru film was formed thereon at an Ar gas pressure of 4.5 Pa.

In examination of the SNRs of the manufactured perpendicular magnetic recording medium of the example and the manufactured perpendicular magnetic recording medium of the comparative example, it was found that the SNR of the former was 18.4 dB and that of the latter was 18.0 dB, respectively. Note that the SNRs were measured by using a spin stand manufactured by Hitachi High-Technologies Corporation under a condition of 1500 kfc.

Thus, the SNR in the case where a material that constitutes the second ground layer contained the Ru—Co oxide alloy (the example) was much better than that in the case where a material that constitutes the second ground layer contained Ru (the comparative example). This is presumably because the second ground layer containing the Ru—Co oxide alloy caused high crystal orientation. Therefore, it is found that the perpendicular magnetic recording medium of the present invention could achieve a higher recording density and a higher SN ratio.

The preferred embodiment of the present invention has been described above with reference to the appended drawings, but it goes without saying that the present invention is not limited to the embodiment. It is obvious that a person skilled in the art can arrive at various modifications or alterations within the scope of claims, and those are of course understood as belonging to the technical scope of the present invention.

## INDUSTRIAL APPLICABILITY

The present invention can be applied to a perpendicular magnetic recording medium installed in an HDD or the like of a perpendicular magnetic recording type and a method of manufacturing the same.

## DESCRIPTIONS OF REFERENCE NUMERALS

- 100**: Perpendicular magnetic recording medium
- 110**: Base plate
- 120**: Adhesive layer
- 130**: Soft magnetic layer
- 140**: Preliminary ground layer
- 150**: Ground layer
- 150a**: First ground layer
- 150b**: Second ground layer
- 160**: Main recording layer
- 170**: Split layer
- 180**: Auxiliary recording layer
- 190**: Protective layer
- 200**: Lubricating layer

The invention claimed is:

1. A perpendicular magnetic recording medium comprising:
  - a base plate, and
  - a laminate film including a first ground layer provided on the base plate, a second ground layer provided on the first ground layer, and a magnetic layer provided on the second ground layer and containing a magnetic material having a granular structure,
    - wherein the magnetic layer contains a CoCrPt alloy, and the second ground layer consists of Ru-xCo<sub>3</sub>O<sub>4</sub>, where x ranges from 0.2 mol to 5 mol,
    - wherein the first ground layer consists of Ru and is thicker than the second ground layer,
    - wherein a film thickness of the second ground layer is 8 nm-15nm,
    - wherein a total film thickness of the first and second ground layers is 11 nm-40 nm, and
    - wherein the first ground layer is formed under a first gas pressure, the second ground layer is formed under a second gas pressure, and the second gas pressure is higher than the first gas pressure.
2. The perpendicular magnetic recording medium according to claim 1, wherein the film thickness of the second ground layer ranges from 8 nm to less than 10 nm.
3. The perpendicular magnetic recording medium according to claim 1, wherein the second ground layer has a granular structure with voids formed between crystal grains that provides separation of the crystal grains and that results from formation under the condition of an Ar atmosphere at a gas pressure in the range of 3 Pa to 10 Pa, being filled with an oxide.
4. The perpendicular magnetic recording medium according to claim 1, further comprising a preliminary ground layer disposed between the base and the first ground layer.
5. The perpendicular magnetic recording medium according to claim 4, wherein the preliminary ground layer has a thickness in a range from 1 nm to 20 nm.
6. The perpendicular magnetic recording medium according to claim 4, wherein the preliminary ground layer comprises Cu, Pt, Pd, Co, Hf or an alloy containing these materials as a main component and added with at least one of V, Cr, Mo and W.

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7. The perpendicular magnetic recording medium according to claim 6, wherein the preliminary ground layer comprises Co.

8. The perpendicular magnetic recording medium according to claim 1, wherein x ranges from 0.2 mol to less than 5 3 mol.

9. The perpendicular magnetic recording medium according to claim 1, wherein the film thickness of the second ground layer is 10 nm-15 nm.

10. The perpendicular magnetic recording medium 10 according to claim 1, wherein x ranges from 0.2 mol to 1.25 mol.

11. The perpendicular magnetic recording medium according to claim 1, wherein x ranges from 0.2 mol to 0.6 15 mol.

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